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THE EFFECT OF IRRIGATING FLOWERING PLANTS AND TURF GRASS WITH CHLORINATED WATER

Report 91-73-K

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ABSTRACT

The effects of irrigating vegetation with chlorinated water was tested on marigolds, snapdragons, impatiens and turf grass. The effects of the chlorination differed between species and growth parameter used. Plant height was the most sensitive indicator, being affected by the addition of sodium hypochlorite to a level of 5 ppm oxidation equivalents of chlorine in marigolds and impatiens. Flower production was inhibited at 5 ppm chlorine in impatiens, but it was not affected by chlorine levels of up to 10 ppm in marigold or snapdragon. Growth of the turf grass was not affected by the chlorine treatments. The results suggest that the 2 ppm level of chlorine used to treat the service water at Ontario Hydro facilities for zebra mussels will not affect vegetation irrigated with this water.

job	file	date	report no.
34-197-241	834.1	April 5, 1991	91-73-K

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EXECUTIVE SUMMARY

THE EFFECT OF IRRIGATING FLOWERING PLANTS AND TURF GRASS WITH CHLORINATED WATER

D. Brown

Ontario Hydro treats its service water to prevent the infestation of the system by zebra mussels. This involves periodic additions of sodium hypochlorite to a level which does not exceed 2 ppm chlorine equivalents at the discharge. At some facilities, this water is used to irrigate lawns and flower beds. The Research Division received a request from the Safety and Environment Dept (Regions Branch) to determine if irrigation with this chlorinated water would adversely affect the growth of the vegetation.

A greenhouse study was designed to determine the effects of chlorination in impatiens, snapdragon, marigold and a Kentucky bluegrass sod. The plants were irrigated with water containing 0, 1, 2, 5 and 10 ppm chlorine for a period of 58 days. Weekly measurements of the height, bud number and flower production, and the final aboveground biomass were determined for the flowers. The effect of chlorine on the grass was determined by assessing the biomass of grass clippings made at 3 times during the study.

Relative to the 0 ppm chlorine controls, total biomass production was not affected by any level of chlorination in the 4 species. Marigold height was reduced by the 5 and 10 ppm treatments after 23 days. Impatiens height was affected by 10 ppm chlorine after 51 days. Flower and bud production was not inhibited in marigold or snapdragon, but was reduced by 2/3 in the impatiens treated with 10 ppm chlorine by day 58. Visual symptoms of the toxic effects involved an increase in leaf discolouration in the marigold at 10 ppm, and curling of the impatiens leaves at 5 and 10 ppm chlorine.

Chlorine additions at a level of 2 ppm did not have any observable affects on the growth or flower production in any of the species tested. It is unlikely that the chlorine level Ontario Hydro is using will have any adverse affects on vegetation irrigated with the service water.

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TO: Mr. B.M. Allen
Vegetation & Animal Control Section
Safety & Environment Department
Regions Branch

1.0 INTRODUCTION

The accidental introduction of zebra mussel, a fresh water mollusc, into Lake St. Clair in 1986, and its subsequent spread to the Great Lakes, has generated concern regarding the supply of service water to Ontario Hydro generating facilities. The prolific growth of the mussels can result in complete blockage of water intakes and systems in a very short time. As a preventive measure, Ontario Hydro has received permission from the Ontario Ministry of the Environment to chlorinate the supply side of its water systems. This involves the addition of sodium hypochlorite (to a level of 2 ppm oxidation equivalents of chlorine) for 30 minutes every 12 hours when the lake water temperature exceeds 12°C (the temperature at which zebra mussels begin to reproduce).

Some concerns have been raised regarding the potential adverse effects of the chlorine on vegetation which is irrigated with this water. There is virtually no information in the literature regarding such effects. A computer survey identified only 1 study on this topic (M.P. Bridgen, 1985, *Connecticut Greenhouse Newsletter* **129**:7-10), which indicated that levels below 5 ppm would not effect zinnia or chrysanthemum. Discussions with researchers in the horticultural field have produced mixed opinions. Dr. Dominic Durkin (Rutgers University) suggested that the 2 ppm level should not affect flowering plants, while Dr. Beverly Hale Marie (University of Guelph) thought that the 2 ppm level of chlorination would adversely affect many species.

Based on these uncertainties, the Research Division received a request from the Vegetation and Animal Control Section, Safety and Environment Department, to investigate the effect of irrigation with chlorinated water on the growth and development of flowering plants and turf grass.

2.0 METHODS

A complete random block design was used, with 5 treatments and 20 blocks. Blocking was required to reduce the effect of variation in plant growth due to light and temperature gradients in the growth facilities.

The treatments consisted of watering plants with a solution of 0, 1, 2, 5 or 10 ppm chlorine oxidation equivalents of sodium hypochlorite (0, 13.4, 26.8, 67.0, or 134 μM NaOCl) 3 times a week for 9 weeks. The flowering plants were seeded in 15 cm pots containing Promix A potting medium and watered with dechlorinated water for 47 days prior to the initiation of the treatments. Thus the plants were at a size comparable to those which are transplanted in spring gardens. Grass sod was similarly planted 25 days prior to the first exposure. Growth room conditions consisted of a day/night temperature of 27°C/15° with a 15 h photoperiod. Light intensities in the growth room ranged from 75 to 125 μmole photons $m^{-2}s^{-1}$. The experiment was transferred to the greenhouse when it became available on day 23 of the treatment. The minimum temperature in the greenhouse was set at 15°C and light intensities of 1,400 μmole photons $m^{-2}s^{-1}$ can be reached on clear days.

The plants used for the study were impatiens (Accent Scarlet #1579), snapdragon (Liberty Lavender #1803), marigold (Perfection Yellow #1666) and petunia (California Girl #1803), grown from seed supplied by Dominion Seed House and a Kentucky bluegrass grass sod supplied from Richmond Hill Sod Co. The petunias were removed from the experiment due to poor germination (38%) and growth.

Weekly measurements were made on the height, bud number and flower number of the snapdragon, impatiens and marigold. Plants were harvested at the end of the experiment and their dry weight (80°C, 24 h) was determined. The grass was mowed on days 16, 43 and 73 of the study to a height of 2-3 cm and dry weight of the clipping were determined (80°C, 12 h).

Some discolouration and curling of the leaves was observed in the marigold and impatiens. The extent of this was visually estimated (% of affected foliage) at the time of harvest.

A 2-way analysis of variance (ANOVA) was used to analyze cumulative and incremental changes in the data. When the ANOVA indicated a significant treatment effect ($p \geq 0.05$) a least significant difference (LSD) multiple range test was performed to determine which treatments differed. The percentage estimates for leaf discolourization and curling was arcsine transformed prior to the ANOVA.

3.0 RESULTS

3.1 Marigold

Figure 1 shows the growth in height of marigolds. These plants were approximately 7 cm tall at the start of the chlorine treatments. Growth occurred at a constant rate during the first 40 days, after which the plants flowered and experienced little subsequent height increases. The height of the plants was strongly affected by the position in the growth room, as indicated by the significant block effect in the ANOVA (Appendix A). This probably reflects a variation in the light intensities in the growth room. The chlorination treatment did not have any observable effect on height until day 23. Following this date, there was

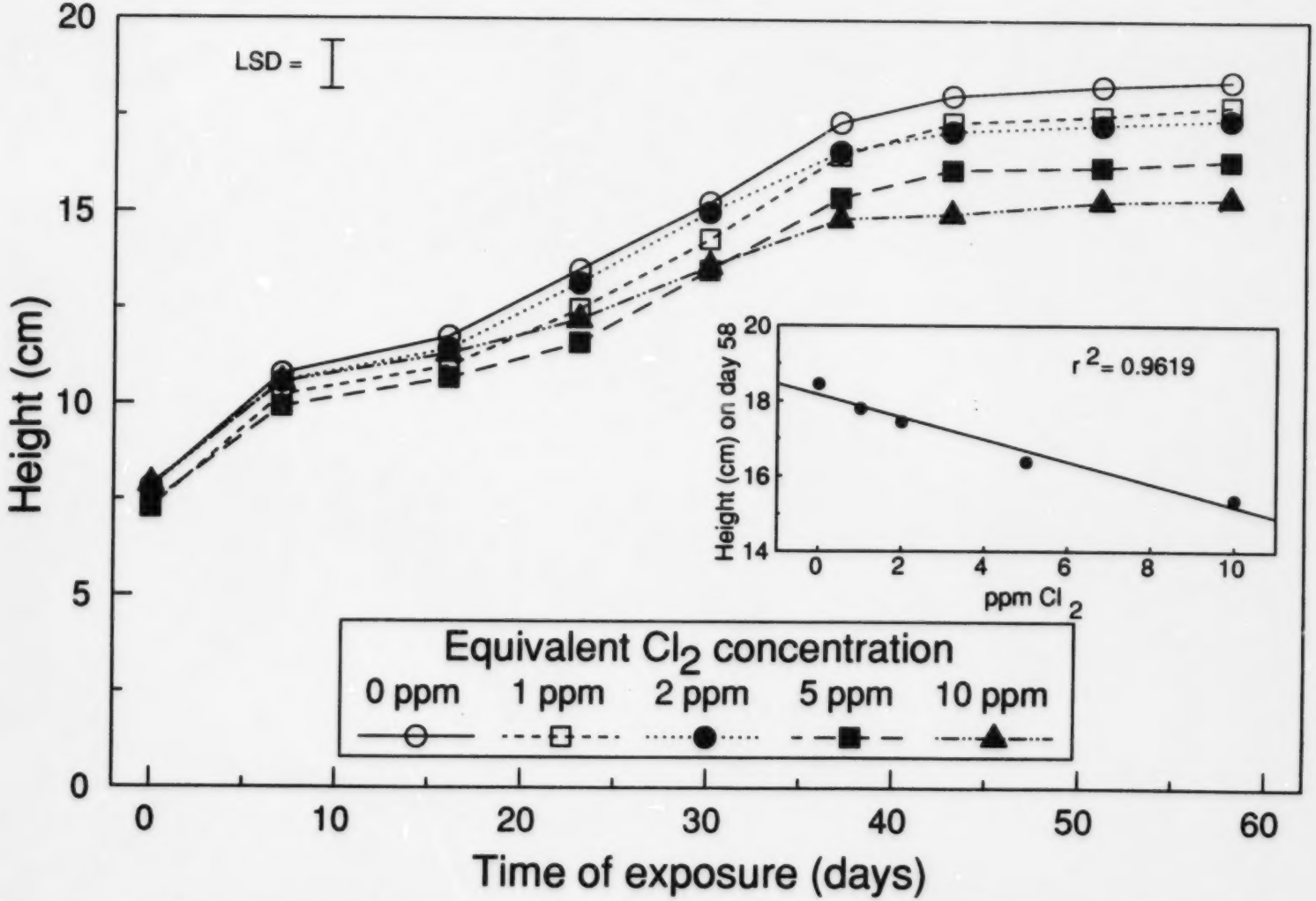

Figure 1: The effect of sodium hypochlorite on the height of marigolds.

Error Bar indicates the least significant difference for day 58

a progressively larger increase in the significance of the treatment effect, as indicated by the F-ratio in the ANOVA (changing from 4.379 on day 23 to 21.024 at the finish of the experiment, appendix A). A reduction in the incremental growth was first observed for the higher chlorine treatments during the 16-23 day period, and this effect was consistently present for the next 3 sampling periods (appendix B), after which it became insignificant.

The marigolds grew best under the 0 ppm chlorine treatment. The height at day 58 decreased linearly with increasing hypochlorite levels ($r^2 = 0.9619$, Figure 1). However, the multiple range test indicated that the height in the 0, 1 and 2 ppm chlorine treatments did not differ significantly from each other on day 58, but did differ from the 5 and 10 ppm treatments.

The above-ground dry weight of the marigolds at the final harvest was also affected by the chlorine treatment (Figure 2, Appendix C). Mean biomass ranged from a high of 8.11 g in the controls to a low of 6.45 g in the 5 ppm treatment. The multiple range test indicated that only the means of the 0 and 5 ppm chlorine treatments differed.

The bud and flower production of the marigolds was not affected by either treatment or blocking in the growth room (Figure 3, Appendix D, E). The number of buds in all treatments increased with time, but the plants did not bloom prior to day 43. With minor exceptions, only 1 flower opened per plant between days 43 and 58, thus flower numbers were not analyzed separately from the bud data. Some foliage discolourization was observed with the marigolds (Figure 4, 5). This ranged from a mean of 10% in the 0 ppm chlorine treatment to 20% in the 10 ppm treatment. These differences are significant (Appendix F). The LSD test indicates that the 0 and 2 ppm treatments experienced less discolourization that the 10 ppm treatment.

3.2 Snapdragon

The height of the snapdragons was strongly affected by the position in the growth room (Appendix A), and averaged 10 cm at the start of the treatments. Height increased linearly until day 23, after which very little growth was observed (Figure 6). The chlorine treatments affected the incremental growth for the periods between days 7-16 and 16-23 (Appendix B), with the intermediate chlorine levels producing the higher growth rates. The total height of the plant was not affected until day 23 ($F = 2.566$, $p = 0.0446$) and the effect became progressively larger as the exposure continued (Appendix A). The effect, however, was not a linear inhibition as observed with the marigolds, but an inverted U-shaped curve, where the poorest growth occurred with the 10 and 0 ppm chlorine treatments (Figure 6). The multiple range test indicated that the only significant differences in the means occurred between the 1 and 10 ppm treatments.

Buds did not form on the snapdragons until the day 7-16 growth period (Figure 7). They increased until day 30, after which the number of buds and flowers exhibited a steady-state condition. At no time in this study were bud and flower numbers affected by the chlorine

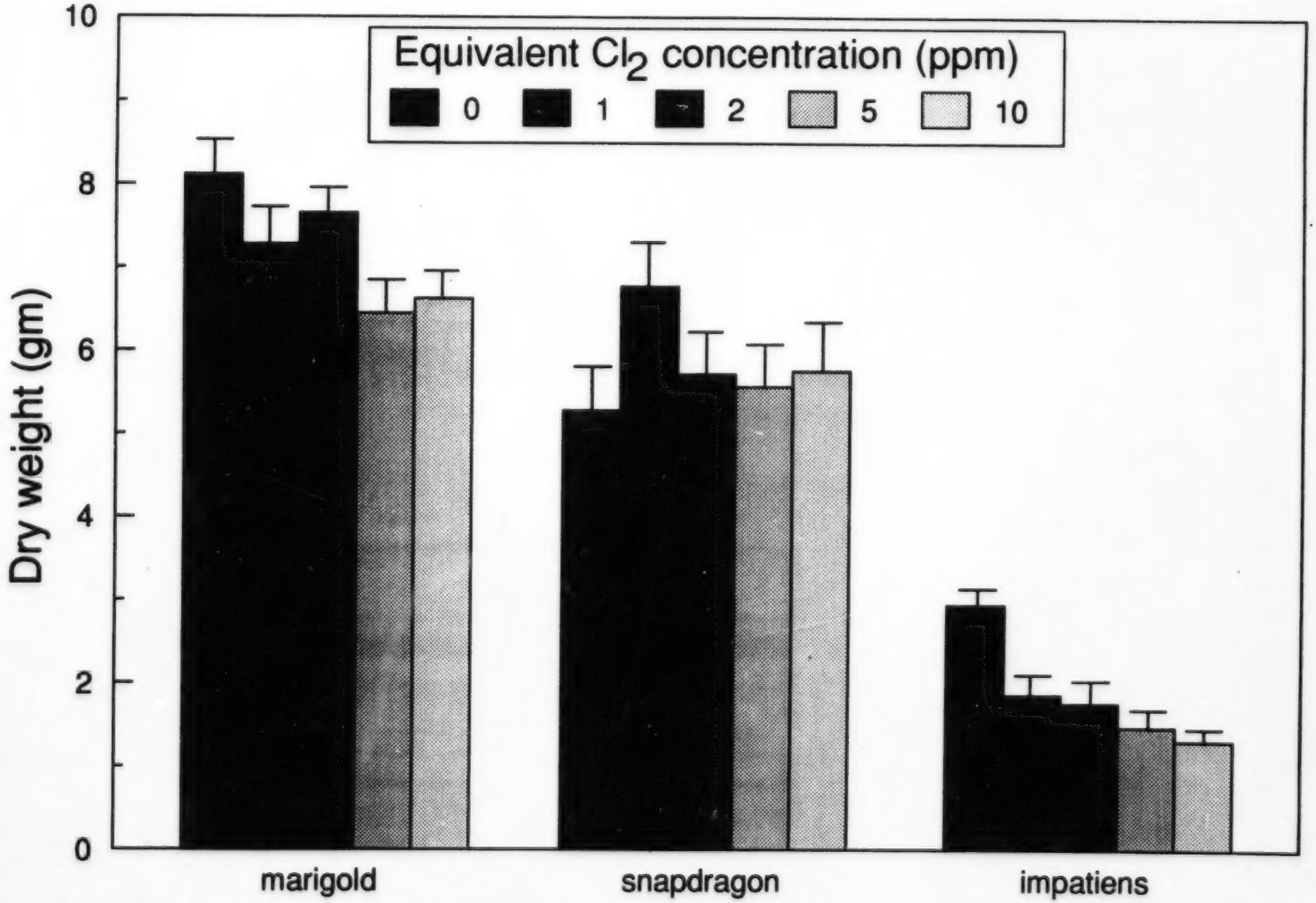

Figure 2: The effect of sodium hypochlorite in the dry weight of flowering plants at the end of harvest.

Error bars indicate the standard error of mean

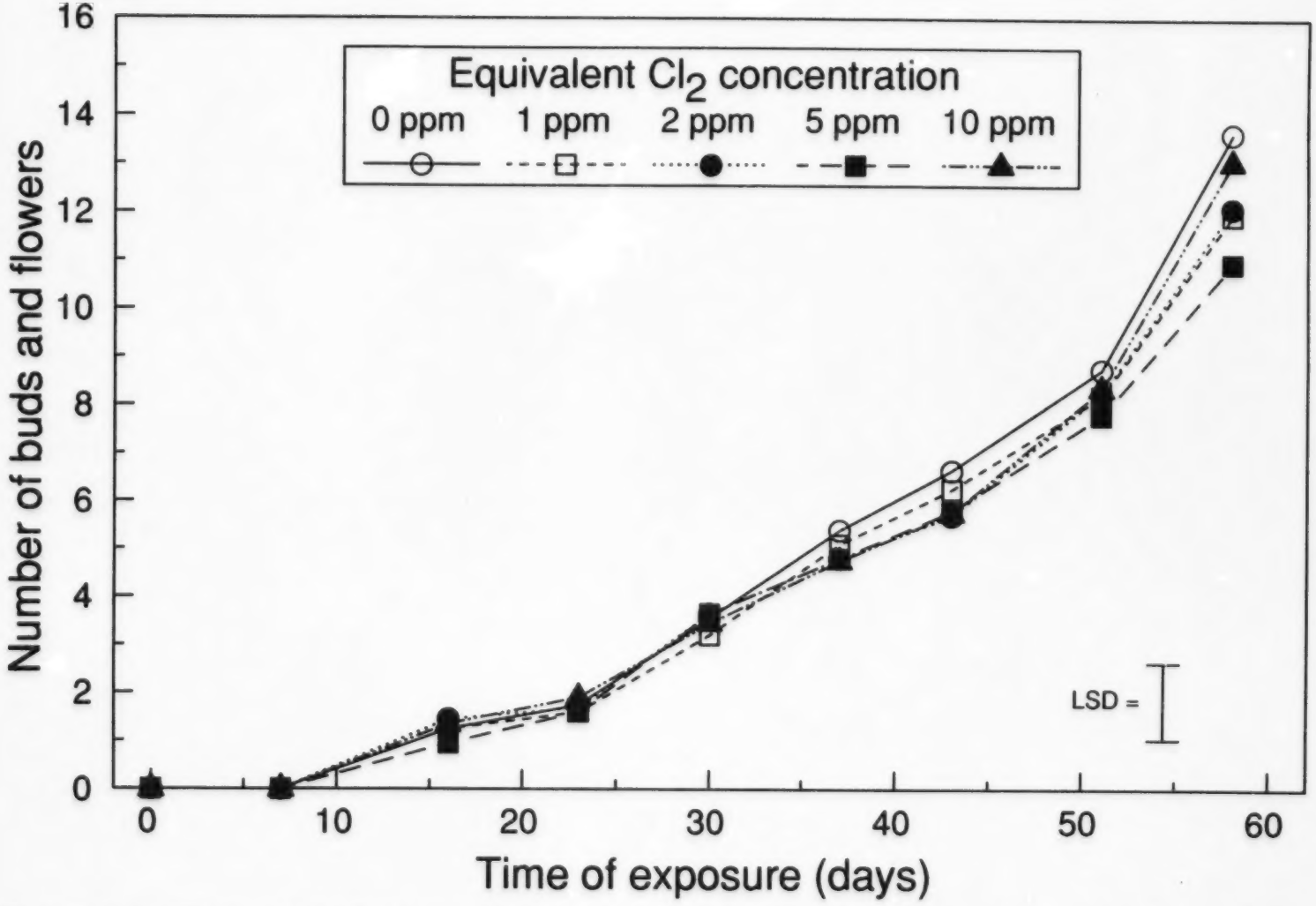

Figure 3: The effect of sodium hypochlorite treatment on the number of marigold buds and flowers.

Error bar indicates the least significant difference for day 58

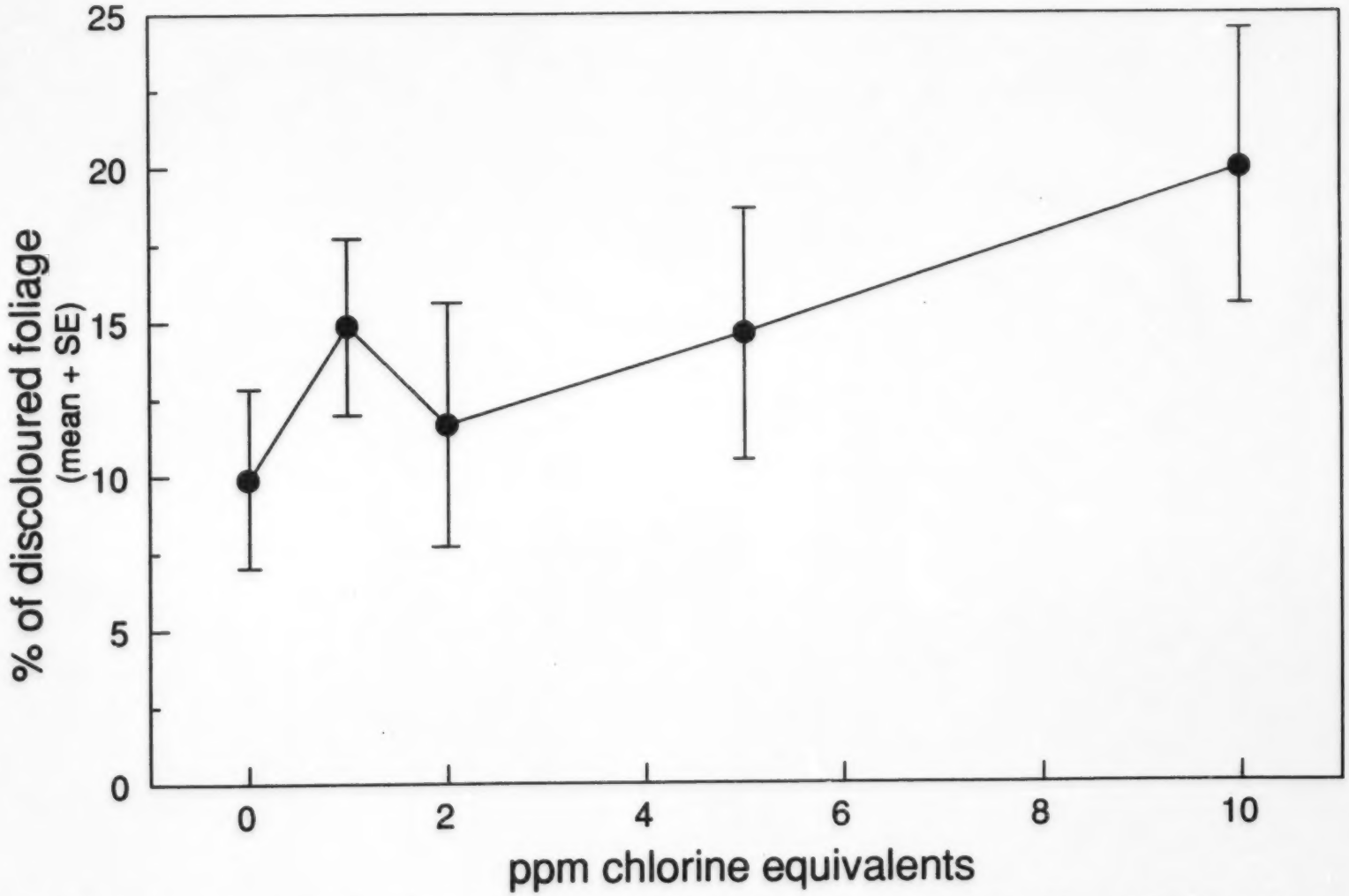

Figure 4: Effect of sodium hypochlorite on the discolouration of marigold leaves.

Visual assessment made at final harvest.

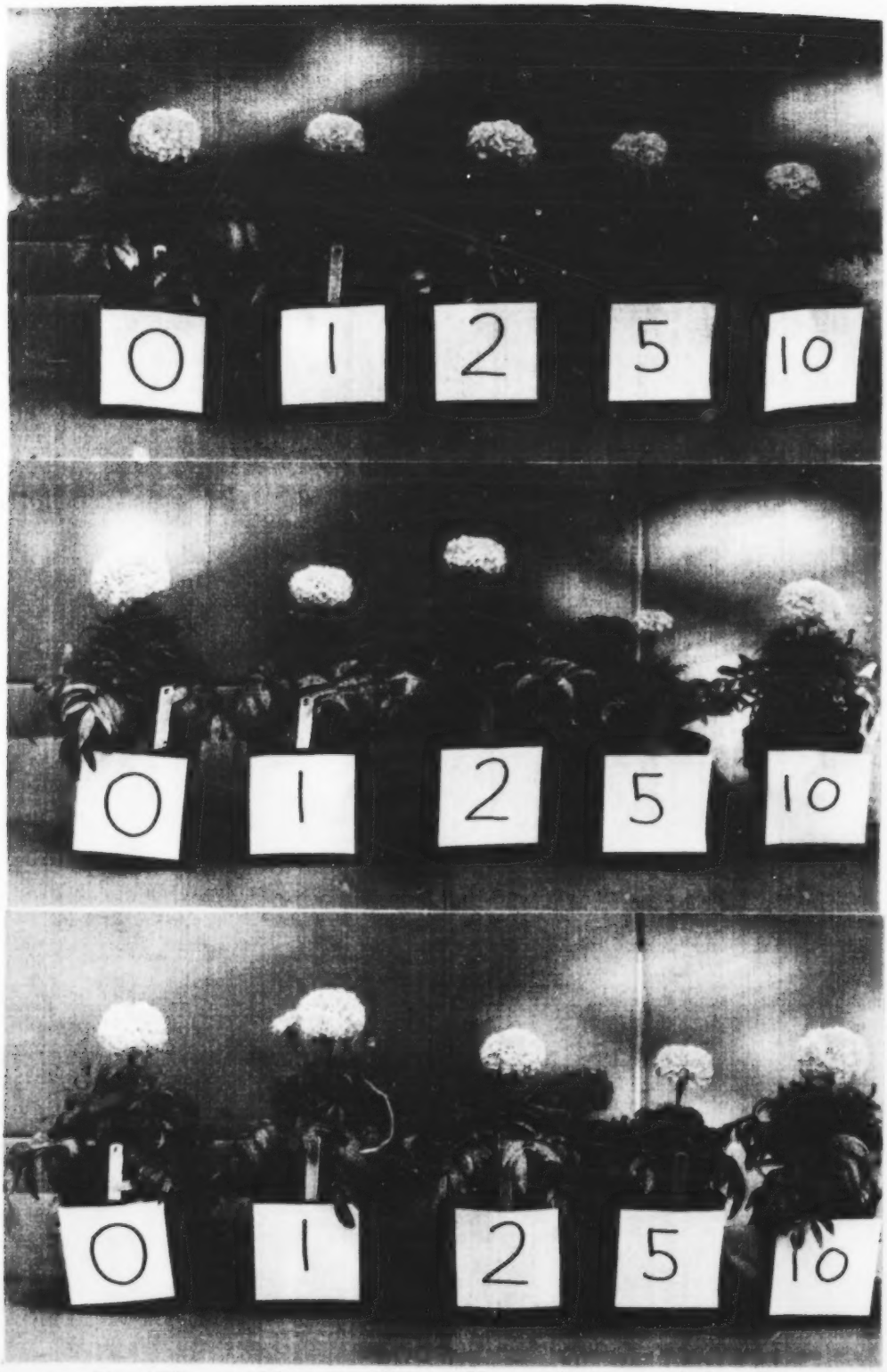

Figure 5: The effect of sodium hypochlorite on the appearance of marigold.

Photographs of 3 randomly selected blocks taken on day 58.

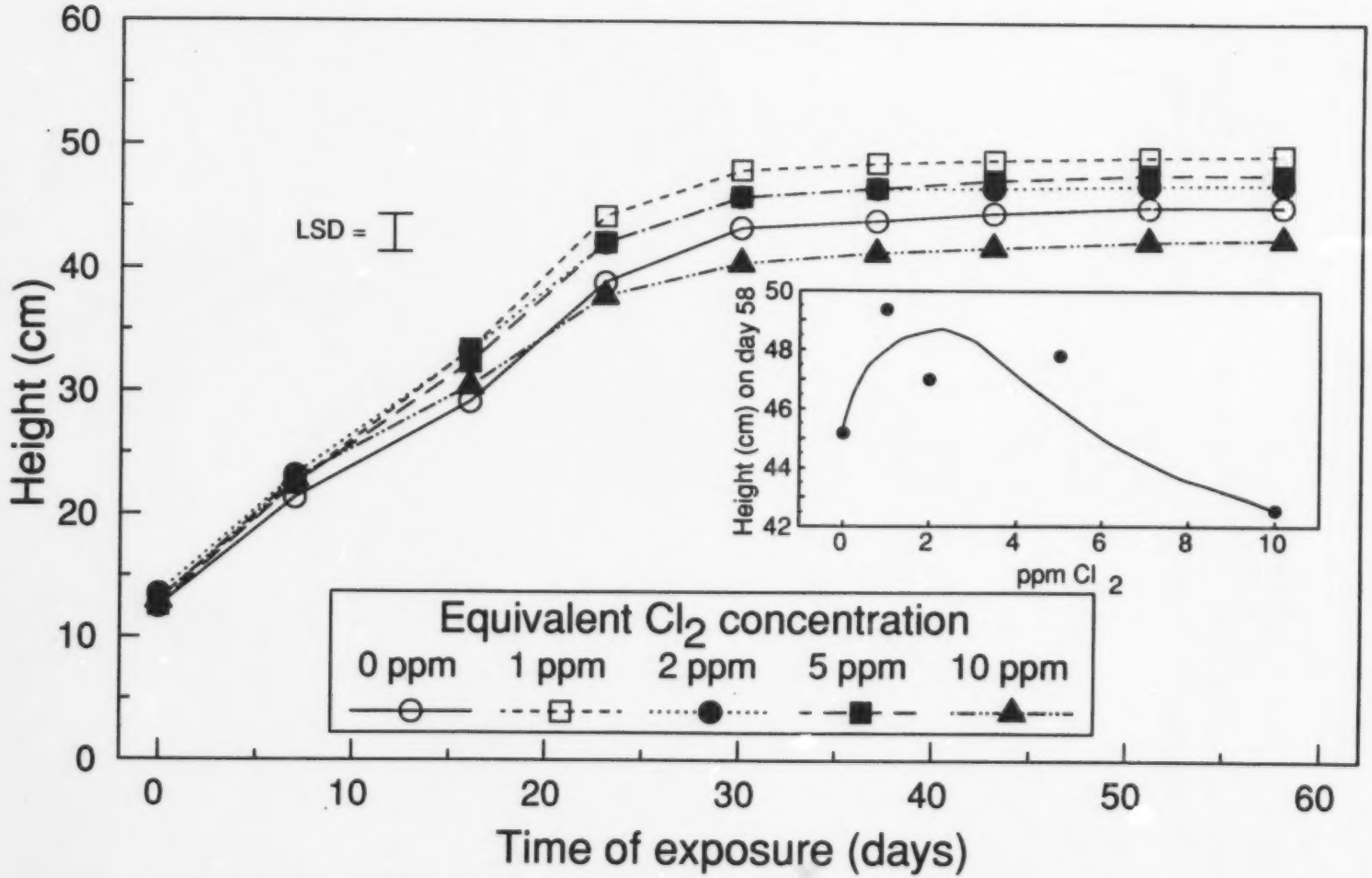

Figure 6: The effect of sodium hypochlorite on the height of snapdragons.

Error bar indicates least significant difference on day 58

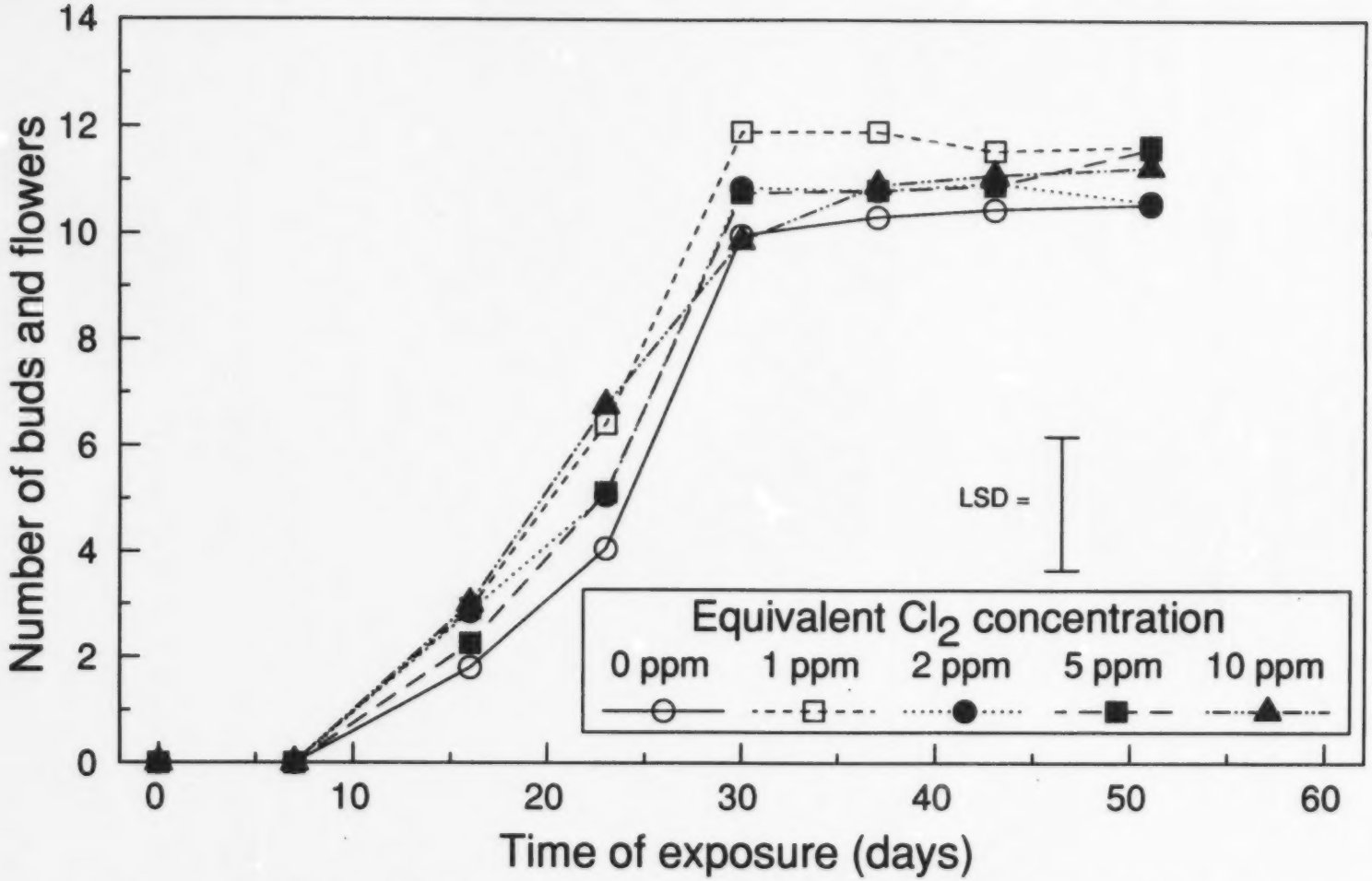

Figure 7: The effect of sodium hypochlorite on snapdragon buds and flowers.

Error bar indicated the least significant differnece on day 58

treatments (Appendix D, E). (The opening of the buds is gradual in this species, making it difficult to delineate a bud from a flower. Thus they were analyzed together in this study.)

There were no observable treatment effects on the snapdragon foliage (Figure 8). Similarly, total above-ground biomass was not affected by the treatments (Figure 2, Appendix C).

3.3 Impatiens

The impatiens grew at a linear rate throughout the study (Figure 9). Unlike the other plants, the ANOVA did not indicate a significant block effect (Appendix A). The total height of the impatiens was not affected by the treatments until day 51. The 0 ppm chlorine level produced the best growth, and increases in hypochlorite concentration decreased growth in a logarithmic manner (r^2 = 0.9245, Figure 9). The only significant differences in the mean growth between treatments was observed on day 51 and 58. The multiple range test indicated that the 0 and 10 ppm chlorine treatments differed on these dates.

The 0 ppm chlorine treatment also produced the largest aboveground biomass in impatiens (Figure 2), although the differences between treatment means were not significant (Appendix C).

Bud formation followed an inverse U-shaped curve, with a maximum in the day 30-37 period (Figure 10). The ANOVA indicated a significant block effect over the first 21 days of the study, but no significant treatment effects were detected (Appendix D).

The chlorine treatments had a large effect on the number of flowers, starting on day 30 (Figure 11, Appendix D, E). The effect increased as the experiment progressed, as indicated by the change in the F-ratio from 2.946 on day 30 to 8.606 in day 58 (Appendix D). Flower number declined with increasing chlorine concentrations in a logarithmic fashion (r^2 = 0.9739, Figure 11). The multiple range test indicated that the mean of the 10 ppm treatment was significantly lower that the 0, 1 and 2 ppm means, and the 5 ppm treatment was lower than the 1 ppm chlorine treatment.

The 5 and 10 ppm chlorine treatments caused some curling of the impatiens leaves (figure 12, 13). The ANOVA indicated that this effect was significant (Appendix F), and the LSD showed that the 10 ppm treatment caused more leaf curling than the 5 ppm treatment, which in turn caused more curling than either the 0, 1 or 2 ppm treatments.

3.4 Grass

A significant block effect was observed in both the cumulative and incremental biomass measurements (Appendix C). There were no significant treatment effects observed at any time (Figure 14, Appendix C), and no visual differences could be observed between the treatments (Figure 15).

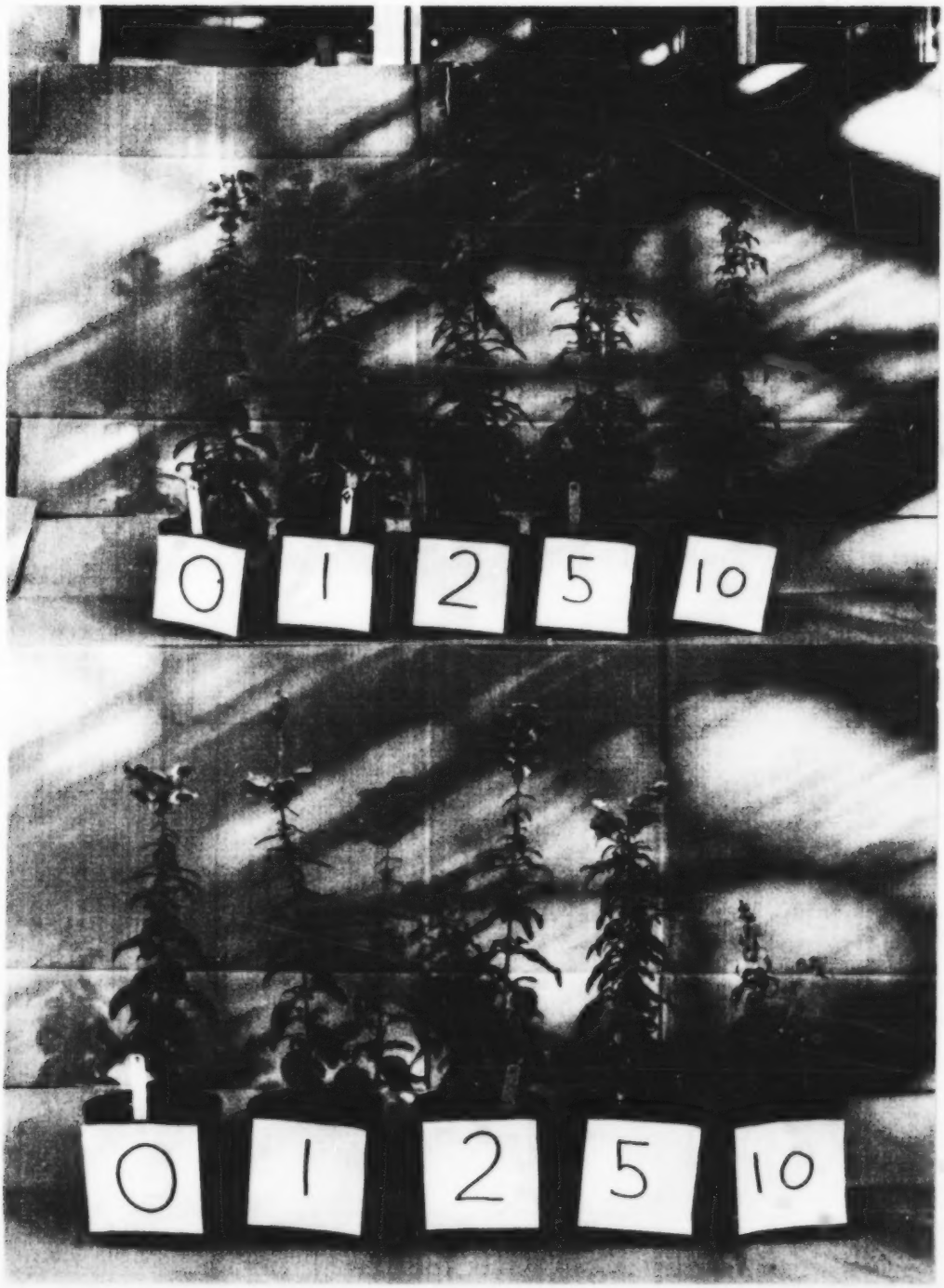

Figure 8: The effect of sodium hypochlorite on the appearance of snapdragon.

Photographs of 2 randomly selected blocks taken on day 58.

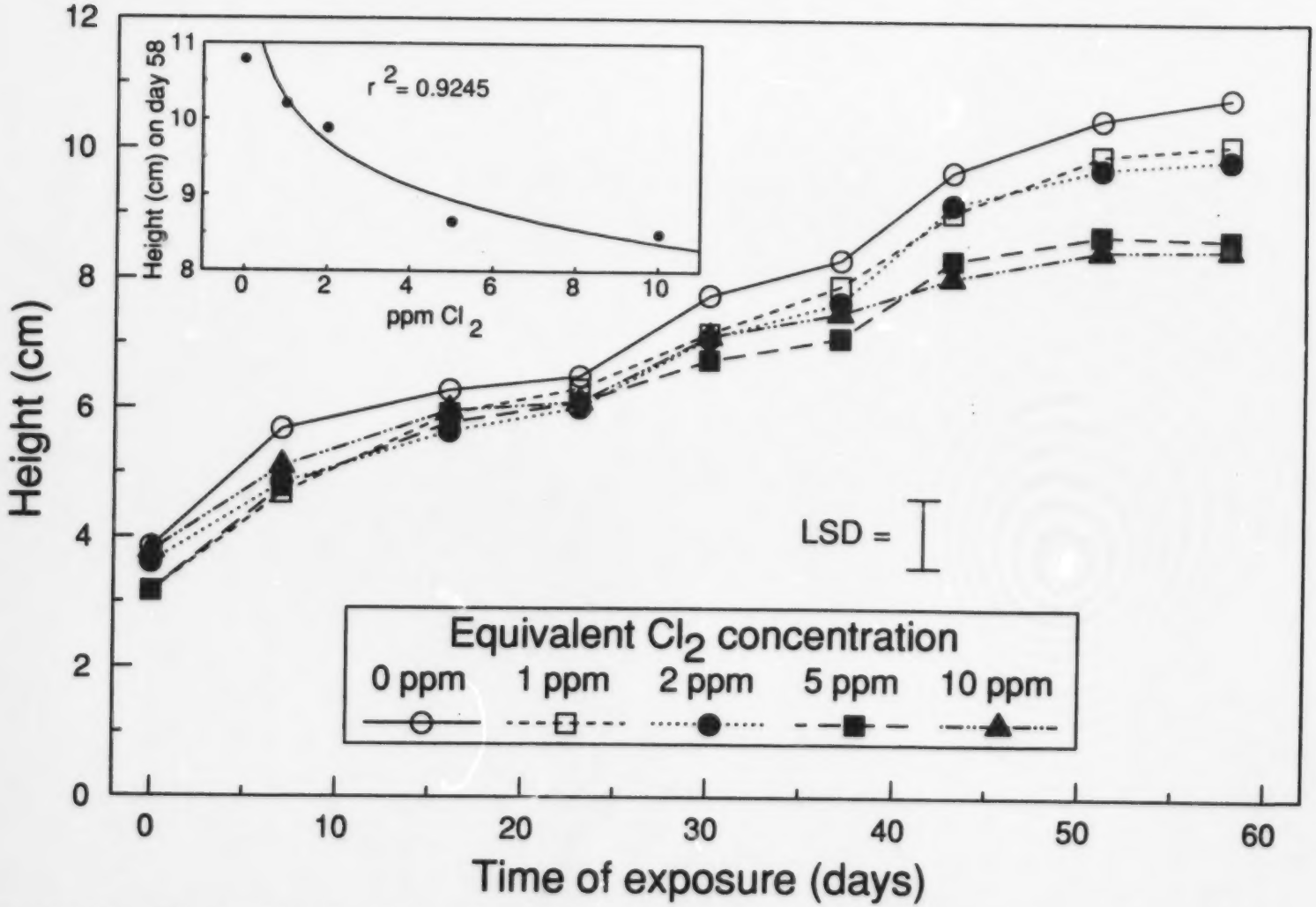

Figure 9: The effect of sodium hypochlorite on the height of impatiens.

Error bar indicates the least significant distance on day 58

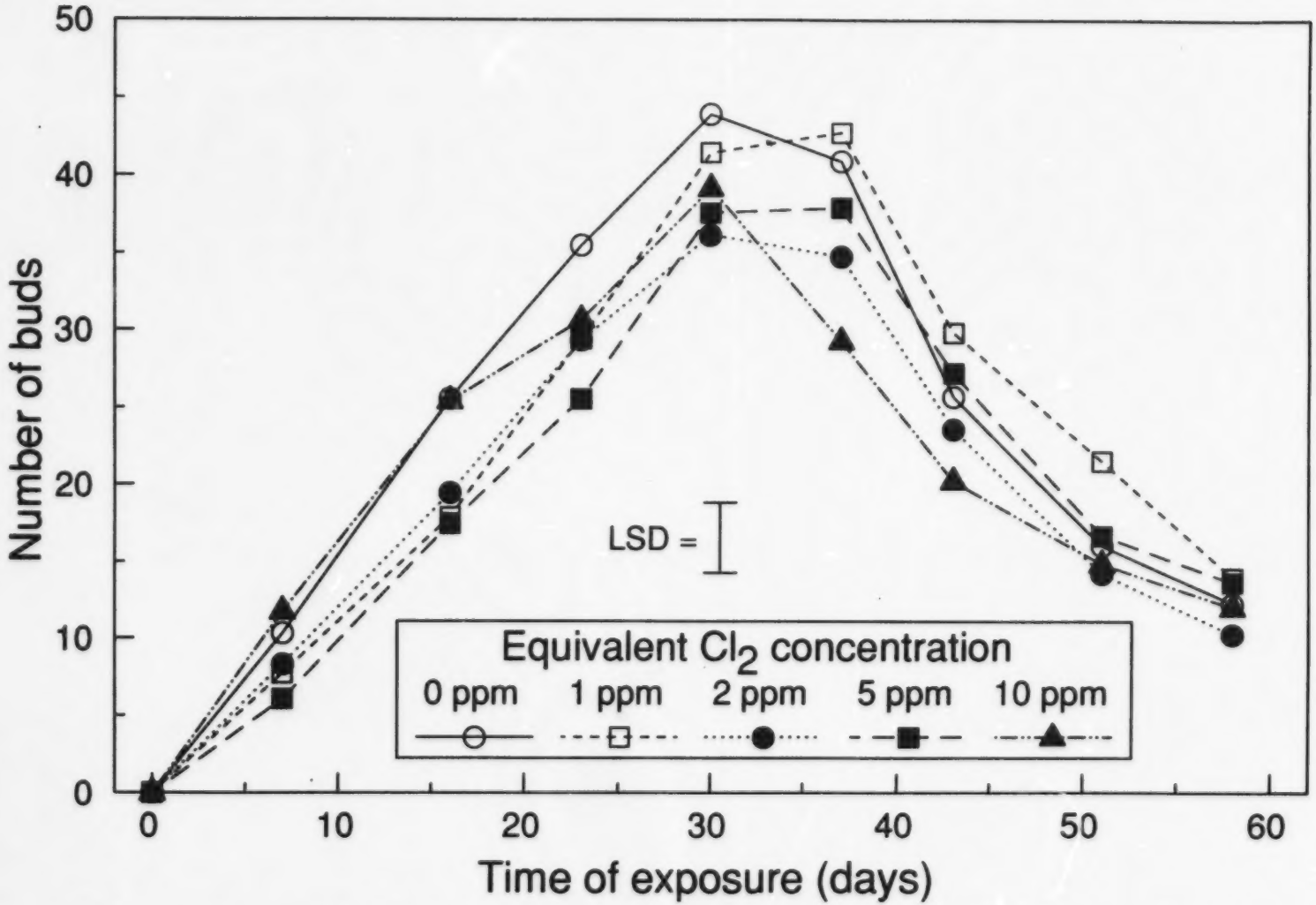

Figure 10: The effect of sodium hypochlorite on the number of impatiens buds.

Effor bars indicate the least significant difference on day 58

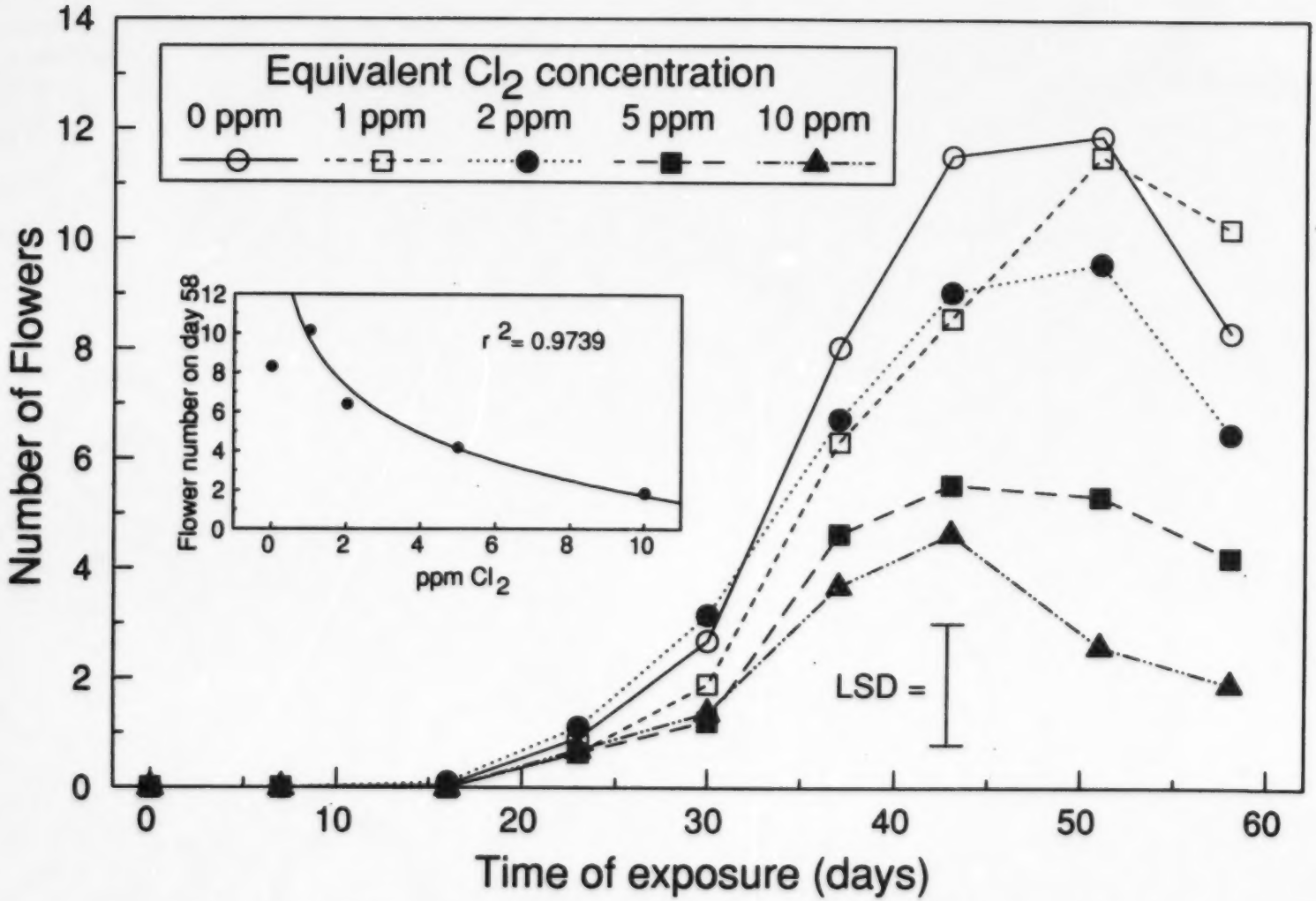

Figure 11: The effect of sodium hypochlorite on the number of impatiens flowers.

Effor bars indicate least sighificant difference on day 58

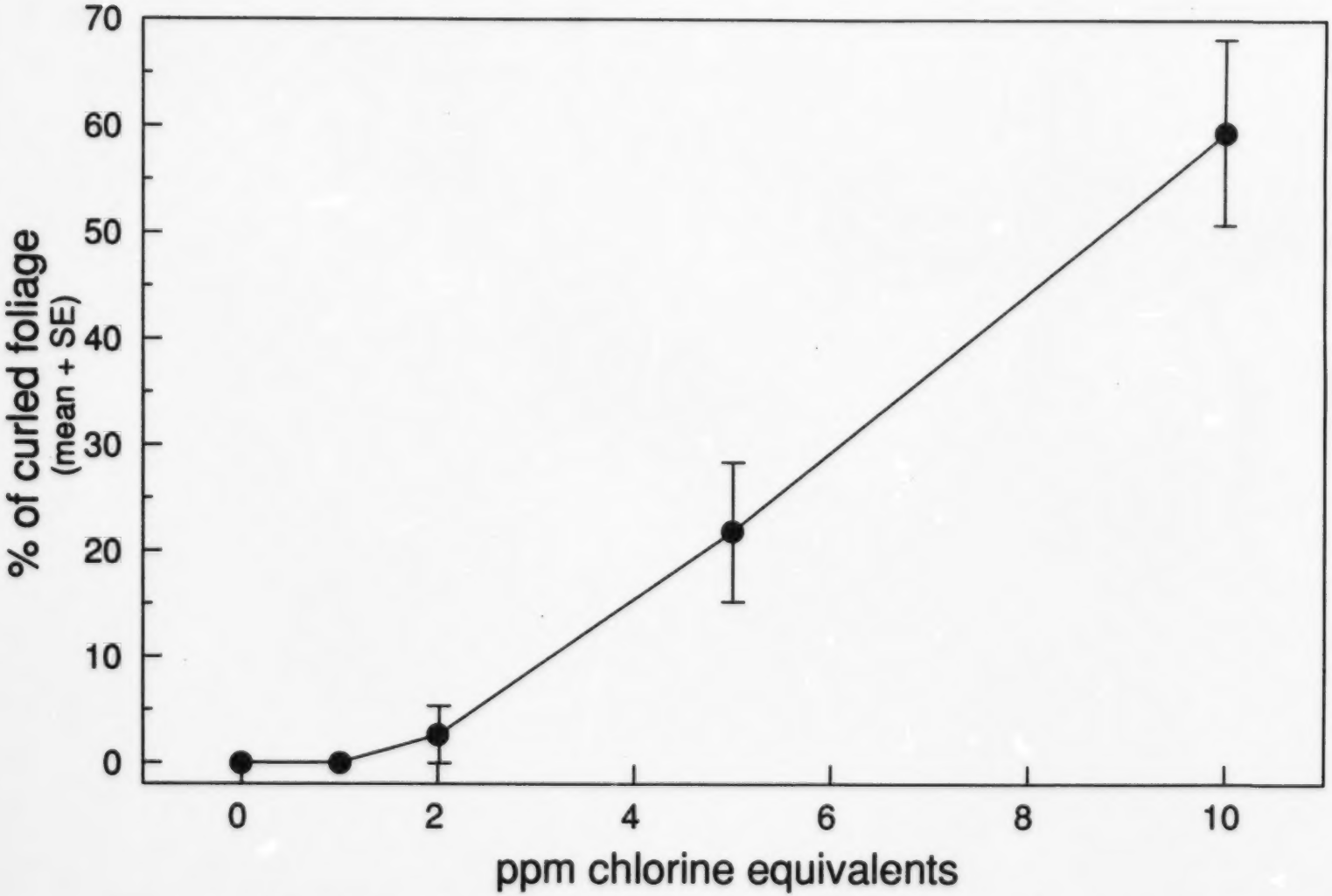

Figure 12: Effect of sodium hypochlorite on the curling of impatiens leaves.

Visual assessment made at final harvest.

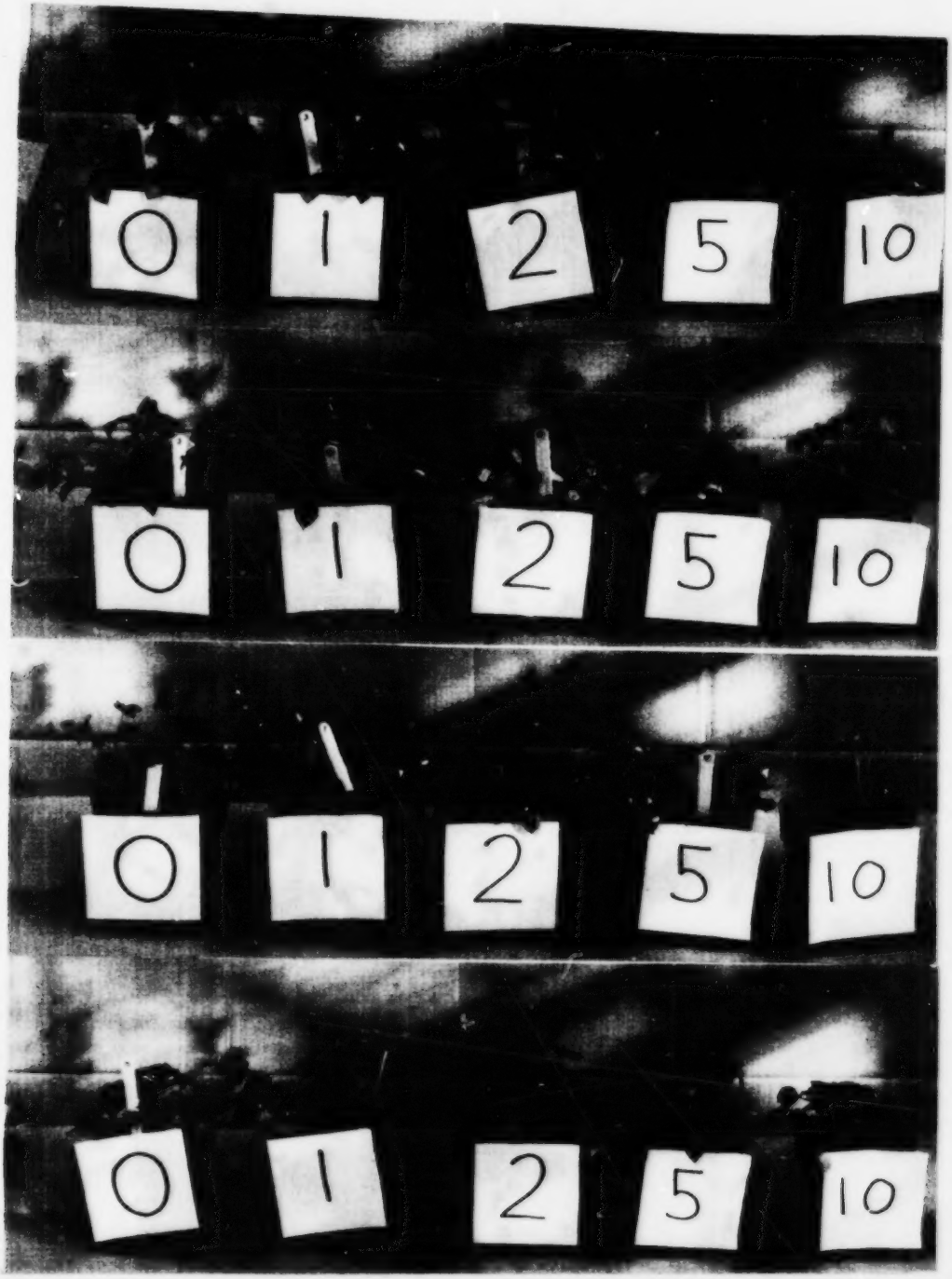

Figure 13: The effect of sodium hypochlorite on the appearance of impatiens.

Photographs of 4 randomly selected blocks taken on day 58.

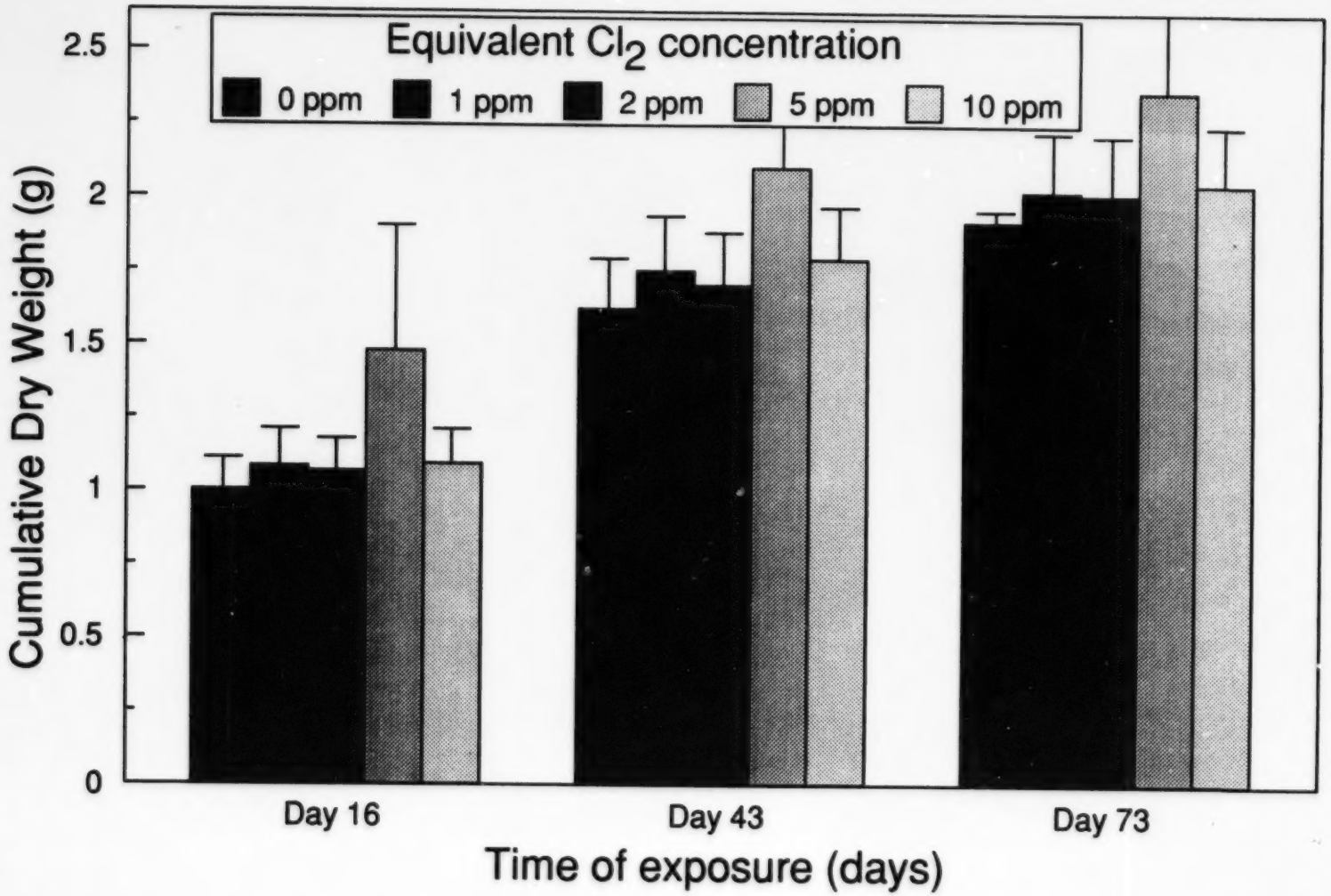

Figure 14: The effect of sodium hypochlorite on the growth of turf grass.

Error bars indicate standard error of mean.

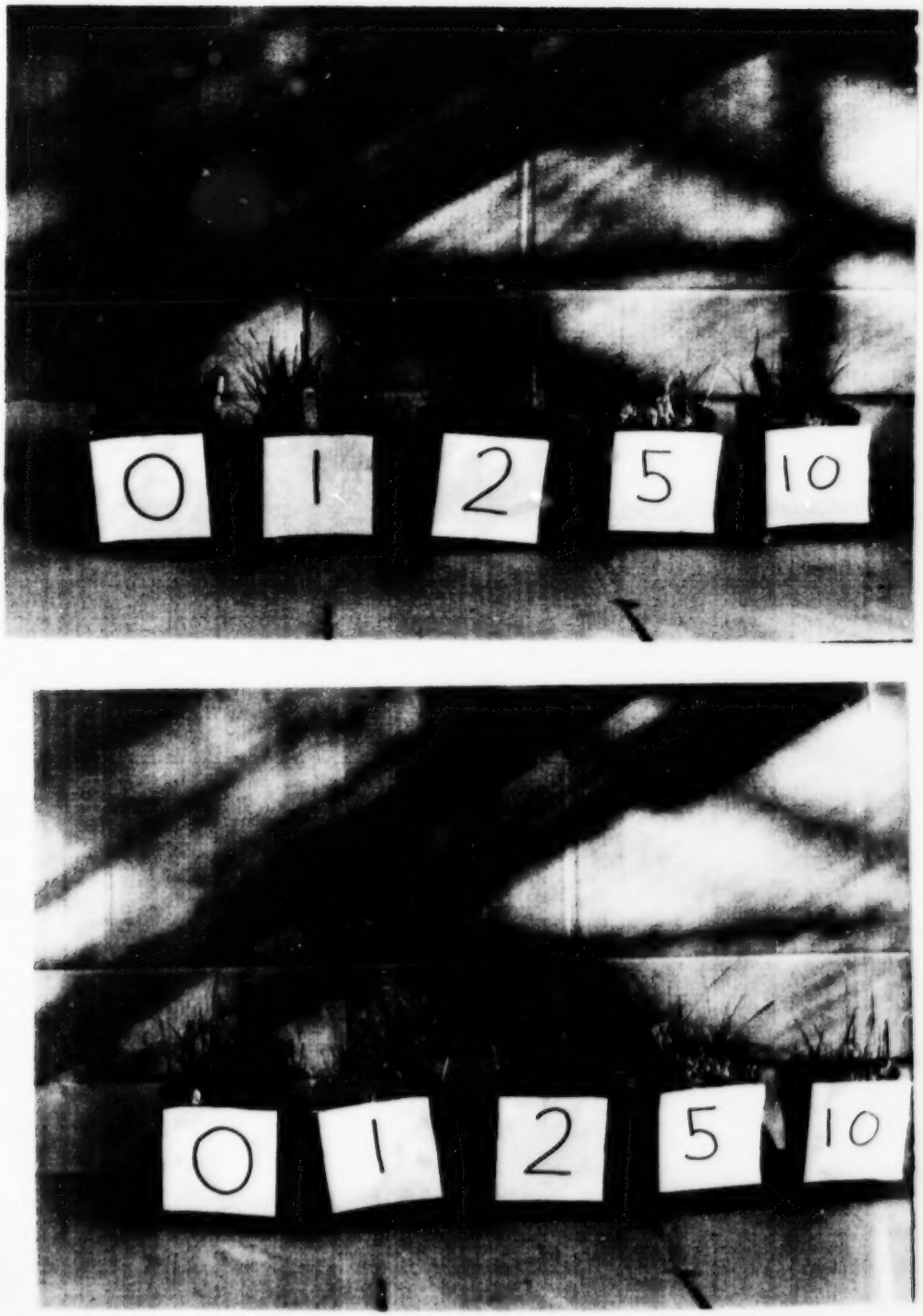

Figure 15: The effect of sodium hypochlorite on the appearance of turf grass.

Photographs of 2 randomly selected blocks taken on day 58.

4.0 DISCUSSION

The effect of hypochlorite irrigation varied considerably between the parameters measured and between species. Height was the growth parameter most frequently affected by chlorine, while the least affected was biomass. Impatiens and marigold were the most sensitive, while the grass was totally unaffected. When significant effects were observed, it was primarily the 10 and/or 5 ppm chlorine treatments that differed from the others. By the end of the study, the height of marigold and impatiens was reduced by 2-3 cm on average in the 10 ppm chlorine treatment (Figure 1, 9), while the number of impatiens flowers declined by approximately two thirds (Figure 11). However, in no instances did the 2 ppm treatment differ from the 0 ppm controls.

This study suggests that it is unlikely that the hypochlorite addition will have an adverse effect on the grass or flower beds irrigated with this water. The plants in this study were constantly exposed to the chlorinated water. This is more severe than that which will be experienced by the vegetation at the stations. Since the chlorine additions used at most locations is intermittent (30 minutes every 12 h), the vegetation will receive water from 3 different sources: irrigation by chlorinated water; irrigation by non-chlorinated water (between chlorination events); and rain water. These alternative water sources will serve to dilute out the chlorine effects. In addition, the higher light levels experienced in the field will also help alleviate the chlorine effects by increasing its rate of breakdown (D. Evans, Process Chemistry, Research Div., Per. Comm.)

There is a remote possibility that the vegetation may be exposed to chlorine levels higher than 2 ppm. This will depend on the configuration of the service water system at each station, specifically the relative location of the hypochlorite injection system and the irrigation system. It is unlikely that chlorine levels in any part of the system will exceed 5 ppm (D. Evans, Per. Comm.). This level may cause a detrimental effect if it was continuously applied (figure 1,3,6,8), but, as discussed above, the possibility of this happening for the 20 plus days necessary to observe an effect is nil. If this is still a concern, then the irrigation events should be timed such that they are out of phase with the chlorination events.

5.0 CONCLUSIONS

1. The sensitivity of continuous irrigation with sodium hypochlorite varied with species. Impatiens and marigolds were the most sensitive, while turf grass and snapdragon were not affected by the treatments.

2. The 2 ppm chlorination level used to treat service water for zebra mussels should not affect the vegetation irrigated with such water.

ACKNOWLEDGEMENTS

I would like to thank Lori Bremner for her assistance with this project.

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Appendix A: The ANOVA results for cumulative growth in height of marigold, snapdragon and impatiens.

Day	ppm (df=4)				Block (df=19)				Error (df= 76)	
	SS	MS	F-ratio	*p*	SS	MS	F-ratio	*p*	SS	MS
Marigold										
0	6.428	1.607	1.688	0.1616	112.566	5.925	6.222	0.0000	72.364	0.952
7	8.990	2.248	1.471	0.2193	48.090	2.531	1.657	0.0639	116.110	1.528
16	13.725	3.431	2.000	0.1030	70.588	3.715	2.166	0.0095	130.375	1.715
23	45.740	11.435	4.379	0.0031	109.828	5.780	2.214	0.0079	198.460	2.611
30	50.360	12.590	3.906	0.0061	136.310	7.174	2.226	0.0076	244.940	3.223
37	80.340	20.085	9.013	0.0000	68.840	3.623	1.626	0.0712	169.360	2.228
43	114.575	28.644	17.973	0.0000	49.488	2.605	1.634	0.0691	121.125	1.594
51	111.150	27.788	19.313	0.0000	46.188	2.430	1.690	0.0568	109.350	1.439
58	118.715	29.679	21.024	0.0000	46.190	2.431	1.722	0.0505	107.285	1.412
Snapdragon										
0	13.365	3.341	1.195	0.3201	323.037	17.003	6.076	0.0000	212.571	2.797
7	38.315	9.579	1.041	0.3916	668.828	35.201	3.827	0.0000	699.085	9.198
16	276.213	69.053	2.121	0.0864	1668.149	87.797	2.696	0.0012	2474.635	32.561
23	552.585	138.146	2.569	0.0446	2236.160	117.693	2.189	0.0087	4086.716	53.882
30	659.940	164.985	3.242	0.0164	1999.290	105.226	2.068	0.0139	3867.360	50.886
37	631.000	157.750	3.617	0.0094	1836.950	96.686	2.217	0.0078	2214.800	43.616
43	593.935	148.484	3.760	0.0076	1721.410	90.601	2.294	0.0058	3000.960	39.483
51	559.125	139.781	3.625	0.0093	1683.388	88.599	2.298	0.0057	2930.675	38.563
58	549.835	137.459	3.649	0.0090	1735.660	91.351	2.425	0.0035	2863.065	37.672
Impatiens										
0	8.265	2.0662	1.094	0.3659	43.508	2.4171	1.280	0.2269	135.939	1.888
7	12.274	3.0684	0.997	0.4148	77.658	4.3143	1.402	0.1573	221.526	3.077
16	4.274	1.068	0.319	0.8644	95.084	5.282	1.577	0.0896	241.126	3.349
23	2.868	0.717	0.214	0.9301	82.589	4.588	1.366	0.1758	241.832	3.359
30	9.905	2.476	0.572	0.6835	116.495	6.483	1.498	0.1160	311.495	4.326
37	15.647	3.912	0.842	0.5033	108.900	6.050	1.302	0.2131	334.653	4.648
43	33.621	8.405	1.623	0.1778	143.332	78.963	1.538	0.1022	372.879	5.178
51	55.658	13.914	2.398	0.0580	188.784	10.488	1.808	0.0407	417.742	5.802
58	75.668	18.917	3.390	0.0134	181.400	10.078	1.806	0.0409	401.731	5.579

Appendix B: The ANOVA results for change in marigold, snapdragon and impatiens height between sampling dates.

Day	ppm (df=4)				Block (df=19)				Error (df= 76)	
	SS	MS	F-ratio	*p*	SS	MS	F-ratio	*p*	SS	MS
Marigold										
0-7	2.517	0.629	0.646	0.6315	47.720	2.512	2.578	0.0019	74.035	0.974
7-16	0.790	0.198	0.251	0.9080	21.828	1.149	1.462	0.1246	59.710	0.786
16-23	14.115	3.528	5.883	0.0004	10.840	0.571	0.951	0.5253	45.585	0.599
23-30	3.210	0.803	1.937	0.1129	9.048	0.476	1.149	0.3231	21.490	0.414
30-37	12.040	3.010	2.374	0.0595	46.490	2.447	1.930	0.2350	96.360	1.268
37-43	6.365	1.591	3.274	0.0157	22.728	1.196	2.461	0.0030	36.935	0.486
43-51	0.700	0.175	0.679	0.6089	5.200	0.274	1.061	0.4065	19.600	0.258
51-58	0.415	0.103	0.617	0.6519	2.828	0.149	0.885	0.6021	12.785	0.168
Snapdragon										
0-7	14.309	3.577	0.854	0.4957	95.044	5.002	1.194	0.2853	318.387	4.189
7-16	178.350	44.588	2.972	0.0245	342.214	18.011	1.201	0.2800	1140.078	15.001
16-23	137.072	34.268	4.477	0.0027	225.854	11.887	1.553	0.0918	581.776	7.655
23-30	30.465	7.616	1.231	0.3050	287.090	15.110	2.442	0.0033	470.335	6.189
30-37	0.840	0.021	0.163	0.9562	37.740	1.986	1.546	0.0940	97.660	1.285
37-43	5.610	1.403	0.743	0.5654	29.360	1.545	0.819	0.6783	143.390	1.887
43-51	1.135	0.284	0.329	0.8574	21.247	1.118	1.298	0.2101	65.465	0.861
51-58	0.485	0.121	0.361	0.8355	6.648	0.349	1.042	0.4261	25.515	0.336
Impatiens										
0-7	4.362	1.090	0.835	0.5073	15.361	0.853	0.654	0.8437	94.002	1.306
7-16	4.147	1.037	2.322	0.0648	21.847	1.214	2.718	0.0014	32.153	0.447
16-23	0.932	0.233	1.227	0.3071	6.726	0.374	1.968	0.0230	13.668	0.189
23-30	3.958	0.989	1.568	0.1922	17.558	0.975	1.546	0.0995	45.552	0.631
30-37	1.963	0.491	1.153	0.3386	6.389	0.355	0.834	0.6552	30.637	0.426
37-43	10.447	2.612	2.873	0.0288	19.232	1.068	1.175	0.3043	65.453	0.909
43-51	3.963	0.991	1.570	0.1915	21.826	1.213	1.921	0.0272	45.437	0.631
51-58	1.721	0.430	2.928	0.0266	2.684	0.149	1.015	0.4545	10.579	0.147

Appendix C: The ANOVA results for growth in above ground biomass of marigold, snapdragon, impatiens and turf grass.

Day	ppm (df=4)				Block (df=19)				Error (df= 76)	
	SS	MS	F-ratio	*p*	SS	MS	F-ratio	*p*	SS	MS
Marigold										
0-66	38.543	9.636	3.014	0.0231	28.316	1.490	0.466	0.9684	242.977	3.197
Snapdragon										
0-63	25.368	6.342	1.534	0.2008	193.653	10.192	2.465	0.0030	314.188	4.134
Impatiens										
0-69	5.452	1.363	1.606	0.1822	17.040	0.9470	1.115	0.3562	61.119	0.849
Turf grass										
0-16	2.866	0.716	1.147	0.3410	37.245	1.960	3.139	0.0002	47.462	0.624
0-43	2.685	0.671	1.001	0.4126	62.443	3.286	4.899	0.0000	50.986	0.671
0-73	2.272	0.568	0.844	0.5017	72.156	3.798	5.641	0.0000	51.162	0.673
0-16	2.866	0.716	1.147	0.3410	37.245	1.960	3.139	0.0002	47.462	0.624
16-43	0.090	0.023	0.507	0.7308	4.377	0.230	5.178	0.0000	3.381	0.045
43-73	0.044	0.011	0.918	0.4578	0.997	0.053	4.411	0.0000	0.904	0.012

Appendix D: The ANOVA results for the number of marigold, snapdragon and impatiens buds and flowers on the sampling date.

Day	ppm (df=4)				Block (df=19)				Error (df= 76)	
	SS	MS	F-ratio	*p*	SS	MS	F-ratio	*p*	SS	MS
Marigold buds and flowers										
16	2.800	0.700	1.928	0.1144	10.350	0.545	1.500	0.1098	27.600	0.361
23	1.240	0.310	0.526	0.7167	12.590	0.663	1.125	0.3448	44.760	0.588
30	12.800	3.200	1.661	0.1678	41.800	2.200	1.142	0.3294	146.400	1.926
37	6.160	1.540	1.705	0.1576	16.110	0.848	0.939	0.5394	68.640	0.903
43	13.460	3.365	2.053	0.0953	20.910	1.101	0.672	0.8349	124.540	1.638
51	9.260	2.315	0.684	0.6051	61.310	3.227	0.954	0.5225	257.140	3.383
58	87.240	21.810	1.728	0.1525	170.040	8.949	0.709	0.7984	959.160	12.620
Snapdragon buds and flowers										
16	21.340	5.335	1.038	0.3933	248.640	13.086	2.546	0.0022	390.660	5.140
23	96.660	24.165	0.985	0.4212	928.910	48.890	1.992	0.0186	1865.340	24.544
30	54.840	13.710	0.674	0.6119	618.040	32.528	1.600	0.0781	1545.560	20.336
37	27.440	6.860	0.342	0.8491	443.640	23.349	1.162	0.3116	1526.560	20.086
43	12.540	3.135	0.180	0.9481	430.590	22.663	1.301	0.2083	1323.860	17.419
51	22.460	5.615	0.411	0.8002	430.510	22.658	1.658	0.0635	1038.340	13.662
58	60.500	15.125	0.482	0.7488	947.800	49.884	1.590	0.0808	2384.700	31.378
Impatiens buds										
7	376.779	94.195	1.476	0.2185	2039.305	113.295	1.775	0.0456	4595.221	63.823
16	1230.779	307.695	1.288	0.2826	8707.726	483.763	2.026	0.0187	17195.221	238.823
23	971.853	242.963	0.646	0.6315	12194.484	677.471	1.801	0.0416	27078.147	376.085
30	731.853	182.963	0.335	0.8533	13006.421	722.589	1.324	0.1993	39286.947	545.652
37	2162.316	540.579	1.636	0.1745	5104.547	283.586	0.858	0.6278	23788.084	330.390
43	1012.568	253.142	1.259	0.2941	2618.947	145.497	0.724	0.7761	14476.632	201.064
51	633.747	158.437	1.007	0.4097	2361.221	131.179	0.834	0.6559	11330.253	157.365
58	133.621	33.406	0.373	0.8274	1494.758	83.042	0.926	0.5506	6453.979	89.638
Impatiens flowers										
16	0.168	0.042	1.655	0.1699	0.905	0.050	1.977	0.2230	1.832	0.025
23	3.263	0.816	0.738	0.5688	38.989	2.166	1.961	0.0236	79.537	1.105
30	53.621	13.405	2.946	0.0259	124.421	6.912	1.519	0.1084	327.579	4.549
37	228.463	57.116	2.224	0.0748	932.126	51.785	2.016	0.0193	1849.726	25.683
43	593.747	148.437	3.743	0.0080	1014.421	56.357	1.421	0.1483	2855.052	39.654
51	1264.063	316.016	8.522	0.0000	497.958	27.664	0.746	0.7527	2669.937	37.082
58	819.411	204.852	8.606	0.0000	141.158	7.842	0.329	0.9947	1713.789	23.803

Appendix E: The ANOVA results for change in marigold, snapdragon and impatiens buds and flower number between sampling dates.

Day	ppm (df=4)				Block (df=19)				Error (df= 76)	
	SS	MS	F-ratio	*p*	SS	MS	F-ratio	*p*	SS	MS
Marigold buds and flowers										
16-23	2.040	0.510	1.591	0.1853	10.440	0.549	1.714	0.0520	24.360	0.320
23-30	9.340	1.597	1.490	0.1006	27.390	1.442	1.345	0.1819	81.460	1.072
30-37	14.460	3.615	3.055	0.0217	35.710	2.827	2.389	0.0044	89.940	1.183
37-43	1.540	0.385	0.360	0.8363	20.840	1.097	1.026	0.4432	81.260	1.069
43-51	7.740	1.935	0.895	0.4711	48.240	2.539	1.175	0.3012	164.260	2.161
51-58	41.660	10.415	1.400	0.2422	125.310	6.595	0.886	0.6001	565.540	7.441
Snapdragon buds and flowers										
16-23	39.940	9.985	0.871	0.4854	328.990	17.315	1.510	0.1061	871.260	11.464
23-30	111.040	27.760	1.416	0.2367	512.590	26.978	1.376	0.1648	1489.760	19.602
30-37	16.760	4.190	0.913	0.4609	120.560	6.345	1.382	0.1616	348.840	4.590
37-43	4.100	10.250	0.899	0.4692	7.950	0.418	0.367	0.9918	86.700	1.141
43-51	11.140	2.785	0.771	0.5473	44.440	2.339	0.648	0.8565	274.460	3.611
51-58	73.060	18.265	1.364	0.2544	213.310	11.227	0.838	0.6560	1017.740	13.391
Impatiens buds										
7-16	329.747	82.437	0.999	0.4139	2968.126	164.896	1.998	0.0206	5941.453	82.520
16-23	438.989	109.747	2.424	0.0558	1635.432	90.857	2.007	0.0200	3259.411	45.269
23-30	419.095	104.774	1.211	0.3138	912.989	50.722	0.586	0.8984	6230.905	86.540
30-37	1486.273	371.568	1.813	0.1356	5359.432	297.746	1.453	0.1341	14753.726	204.913
37-43	418.674	104.668	0.746	0.5639	2674.400	148.578	1.059	0.4097	10102.126	140.307
43-51	301.726	75.432	0.951	0.4398	2157.032	119.835	1.511	0.1115	5711.074	79.320
51-58	251.221	62.805	1.464	0.2220	460.232	25.568	0.596	0.8910	3087.979	42.889
Impatiens flowers										
16-23	1.958	0.489	0.481	0.7494	34.232	1.902	1.870	0.0327	73.242	1.017
23-30	32.358	8.089	3.347	0.0143	36.484	2.027	0.839	0.6503	174.042	2.417
30-37	99.537	24.884	1.593	0.1855	429.558	23.864	1.528	0.1056	1124.863	15.623
37-43	88.695	22.174	1.329	0.2676	189.558	10.531	0.631	0.8634	1201.705	16.690
43-51	244.316	61.079	3.032	0.0228	413.726	22.985	1.141	0.3333	1450.484	20.146
51-58	819.411	204.853	8.606	0.0000	141.158	7.842	0.329	0.9947	1713.789	23.803

Appendix F: The ANOVA results for a visual assessment of leaf discolourization or curling in marigold and impatiens at final harvest.

Day	ppm (df=4)				Block (df=19)				Error (df= 76)	
	SS	MS	F-ratio	*p*	SS	MS	F-ratio	*p*	SS	MS
Marigold leaf discolourization										
0-53	704.209	176.052	2.640	0.0401	13073.418	688.075	10.319	0.000	5067.646	66.679
Impatiens leaf curling										
0-53	38651.531	9662.883	28.861	0.000	6248.317	347.129	1.037	0.4319	24106.375	334.811